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Patentanmeldung Nr. Patent application No. Demande de brevet n°

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Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
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Page 2 de l'attestation

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See for original title of the application
page 1 of the description.

DOSE CONTROL IN LITHOGRAPHIC APPARATUS

The present invention relates to dose sensing and control in a lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first object table for holding a mask;

a second, movable object table for holding a substrate; and

a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate.

For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, catadioptric systems, and charged particle optics, for example. The illumination system may also include elements operating according to any of these principles for directing, shaping or controlling the projection beam of radiation. In addition, the first and second object tables may be referred to as the "mask table" and the "substrate table", respectively.

Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the mask (reticle) may contain a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto a target portion (comprising one or more dies) on a substrate (silicon wafer) which has been coated with a layer of radiation-sensitive material (resist). In general, a single substrate will contain a whole network of target portions which are successively irradiated via the mask, one at a time. In one type of lithographic projection apparatus, each target portion is irradiated by exposing the entire mask pattern onto the target portion in one go; such an apparatus is commonly referred to as a wafer stepper. In an alternative apparatus — which is commonly referred to as a step-and-scan apparatus — each target portion is irradiated by progressively scanning the mask pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the substrate table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the substrate table is scanned will be a factor M times that at which the mask table is scanned. More information with regard to lithographic devices as here described can be gleaned from International Patent Application WO 97/33205.

In general, apparatus of this type contained a single first object (mask) table and a single second object (substrate) table. However, machines are becoming available in which there are at least two independently movable substrate tables; see, for example, the multi-stage apparatus described in International Patent Applications WO 98/28665 and WO 98/40791. The basic operating principle behind such multi-stage apparatus is that, while a first substrate table is underneath the projection system so as to allow exposure of a first substrate located on that table, a second substrate table can run to a loading position, discharge an exposed substrate, pick up a new substrate, perform some initial metrology steps on the new substrate, and then stand by to transfer this new substrate to the exposure position underneath the projection system as soon as exposure of the first substrate is completed, whence the cycle repeats itself; in this manner, it is possible to achieve a substantially increased machine throughout, which in turn improves the cost of ownership of the machine.

In a lithographic projection process it is important to control accurately the dose (i.e. amount of energy per unit area integrated over the duration of the exposure) delivered to the resist. Known resists are designed to have a relatively sharp threshold whereby the resist is exposed if it receives an amount of energy per unit area above the threshold but remains unexposed if the amount of received energy is less than the threshold. This is used to produce sharp edges in the features in the developed resist even when diffraction effects cause a gradual tail-off in intensity of the projected images at feature edges. If the beam intensity is too incorrect, the exposure intensity profile will cross the resist threshold at the wrong point. Dose control is thus crucial to correct imaging.

In a known lithographic apparatus dose control is done by monitoring the beam intensity at a point in the illumination system and calibrating the absorption of the apparatus between that point and the substrate level. Monitoring the beam intensity is performed using a partially transmissive mirror to divert a known fraction of the projection beam in the illumination system to an energy sensor. The energy sensor measures the energy in the known fraction of the beam and so enables the beam energy at a given point in the illumination system to be determined. The calibration of the absorption of the apparatus, downstream of the partially transmissive mirror, is done by replacing the substrate by an energy sensor for a series of calibration runs. The output of the energy sensor effectively measures variations in the output of the radiation source and is combined with the calibration results of the absorption of the downstream parts of the apparatus to predict the energy level at substrate level. In some cases the prediction of the energy level at substrate level may take account of parameters of the exposure, e.g. illumination system settings. The exposure parameters, e.g. duration or scanning

speed, and/or the output of the radiation source can then be adjusted to deliver the desired dose to the resist.

Whilst the known method of dose control takes account of variations in the output of the radiation source and deals well with predictable variations in absorption downstream of the energy sensor, not all variations in absorption are easily or accurately predictable. This is particularly the case for apparatus using exposure radiation of shorter wavelengths, which are essential to reduce the size of the smallest features that can be imaged, such as 157nm, 126nm or EUV (less than 50nm). Such wavelengths are heavily absorbed by air and many other gases so that lithographic apparatus making use of them must be either flushed with non-absorbing gases or evacuated. Any variations in the composition of the flushing gas or leaks from the outside can result in significant and unpredictable variations in the absorption of the beam in the downstream parts of the apparatus and hence of the dose delivered to the resist.

An object of the present invention is therefore to provide an improved dose sensing and control system which avoids or alleviates the problems of known energy sensors and dose control systems.

According to the present invention there is provided a lithographic projection apparatus for imaging of a mask pattern in a mask onto a substrate provided with a radiation-sensitive layer, the apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first object table for holding a mask;

a second object table for holding a substrate; and

a projection system for imaging irradiated portions of the mask onto target portions of the substrate; characterized by:

an acoustic sensor constructed and arranged to detect sounds caused by the passage of pulses of the projection beam.

The acoustic sensor, which may be a microphone, a (micro-)barograph or a vibration sensor, detects sounds caused by the passage of the pulses of the projection beam. These sounds are an effect of localized heating caused when energy from the pulse is absorbed in the atmosphere through which it passes, or by an object on which it is incident, e.g. an optical element in the projection lens or the substrate itself. The magnitude of the sounds detected can be used to detect changes in the intensity of the projection beam or the presence of contaminants and can thus be used to improve dose control.

The invention is particularly advantageous when used to detect vibrations caused by the arrival of beam pulses at the substrate or their passage through a chamber between the last element of the projection lens and the substrate. In this case, the invention provides a direct measurement of the beam intensity at substrate level allowing for particularly accurate dose control.

According to a further aspect of the invention there is provided a method of manufacturing a device using a lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first object table for holding a mask;

a second object table for holding a substrate; and

a projection system for imaging irradiated portions of the mask onto target portions of the substrate; the method comprising the steps of:

providing a mask bearing a pattern to said first object table;

providing a substrate provided with a radiation-sensitive layer to said second object table;

irradiating portions of the mask and imaging said irradiated portions of the mask onto said target portions of said substrate; characterized by the step of:

using an acoustic sensor to detect vibrations caused by the passage of pulses of said projection beam.

In a manufacturing process using a lithographic projection apparatus according to the invention a pattern in a mask is imaged onto a substrate which is at least partially covered by a layer of radiation-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallisation, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4.

Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion" or "exposure area", respectively.

In the present document, the terms radiation and projection beam are used to encompass all types of electromagnetic radiation or particle flux, including, but not limited to, ultraviolet radiation (e.g. with a wavelength of 157 or 126 nm), EUV and X-rays.

The present invention will be described below with reference to exemplary embodiments and the accompanying schematic drawings, in which:

Figure 1 depicts a lithographic projection apparatus according to a first embodiment of the invention;

Figure 2 is a plan view of an energy sensor used in the apparatus of Figure 1;

Figure 3 is a side view of the energy sensor of Figure 2;

Figure 4 is a diagram of a control system in the apparatus of Figure 1;

Figure 5 is side view of part of a lithographic apparatus according to a second embodiment of the invention;

Figure 6 is a side view of part of a lithographic apparatus according to a third embodiment of the invention;

Figure 7 is a side view of part of a lithographic apparatus according to a fourth embodiment of the invention; and

Figure 8 is a side view of part of a lithographic apparatus according to a fifth embodiment of the invention.

In the drawings, like reference numerals indicate like parts.

Embodiment 1

Figure 1 schematically depicts a lithographic projection apparatus according to the invention. The apparatus comprises:

- a radiation system LA, IL for supplying a projection beam PB of radiation (e.g. UV or EUV radiation);
- a first object table (mask table) MT provided with a mask holder for holding a mask MA (e.g. a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL;
- a second object table (substrate table) WT provided with a substrate holder for holding a substrate W (e.g. a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;
- a projection system ("lens") PL (e.g. a refractive or catadioptric system, a mirror group or an array of field deflectors) for imaging an irradiated portion of the mask MA onto a target portion C of the substrate W.

As here depicted, the apparatus is of a transmissive type (i.e. has a transmissive mask). However, in general, it may also be of a reflective type, for example.

In the example depicted here, the radiation system comprises a source LA (e.g. a Hg lamp, excimer laser, a laser or discharge plasma source or an undulator provided around the path of an electron beam in a storage ring or synchrotron which produces a beam of radiation. This beam is passed along various optical components comprised in the illumination system IL, — e.g. beam shaping optics Ex, an integrator IN and a condenser CO — so that the resultant beam PB has a desired shape and intensity distribution.

The beam PB subsequently intercepts the mask MA which is held in a mask holder on a mask table MT. Having passed through the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto a target portion C of the substrate W. With the aid of the interferometric displacement measuring means IF, the substrate table WT can be moved accurately by the second positioning means, e.g. so as to position different target portions C in the path of the beam PB. Similarly, the first positioning means can be used with the aid of interferometric displacement measuring means to accurately position the mask MA with respect to the path of the beam PB, e.g. after mechanical retrieval of the mask MA from a mask library. In general, movement of the object tables MT, WT will be realized with the aid of a long stroke module (course positioning) and a short stroke module (fine positioning), which are not explicitly depicted in Figure 1.

The depicted apparatus can be used in two different modes:

1. In step mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go (i.e. a single "flash") onto a target portion C. The substrate table WT is then shifted in the x and/or y directions so that a different target portion C can be irradiated by the beam PB;

2. In scan mode, essentially the same scenario applies, except that a given target portion C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", e.g. the x direction) with a speed v, so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed V = Mv, in which M is the magnification of the lens PL (typically, M = -1/4 or -1/5). In this manner, a relatively large target portion C can be exposed, without having to compromise on resolution.

Figures 2 and 3 show an arrangement of an energy sensor used to measure the intensity of the projection beam PB. The projection beam PB is arranged to pass through one focus of an elliptical chamber 10 filled with a gas of a known composition whilst a microphone or micro-barograph 20 is placed at the other focus. The composition of the gas in the chamber is dependent on the wavelength of the projection beam and is selected to have known and predictable absorption properties. Where the projection beam has a wavelength of 157nm, the gas may be N_2, which is essentially transparent to 157nm radiation, mixed with a known amount of O_2, which strongly absorbs 157nm radiation. Since almost all gases are strongly absorptive of EUV, any convenient gas can be used in an apparatus using EUV radiation and it is most important to know the density of the gas in chamber 10. It should be noted that the absorbing gas may be deliberately introduced for the purpose of the present invention or for some other purpose such as cleaning, or may be an unavoidable residue left behind by the evacuation or purging system.

Because the gas in chamber 10 absorbs radiation from the projection beam, when beam pulse passes through the chamber 10, it will cause localized heating of the gas leading to a local pressure increase and creating a sound wave. The pressure increase and/or sound wave is then detected by the microphone or micro-barograph 20. Because the chamber is elliptical, any sound wave generated at one focus, where the projection beam passes, is focused at the other focus at which the microphone or micro-barograph 20 is located. The size of the pressure change and/or intensity of the sound wave will depend on the intensity of the projection beam pulse and the absorption properties of the gas in chamber 10. Knowledge of these properties, derived theoretically and/or empirically, allows the beam pulse intensity to be calculated from the output of the microphone or micro-barograph 20. Calculation of the beam intensity may take account of other measurements, e.g. of temperature, made by sensors 21 also provided in chamber 10. The history of previous intensity measurements may also be taken into account.

The energy sensor arrangement shown in Figures 2 and 3 can be located in any convenient location in the beam path between radiation source LA and substrate W. To provide the most accurate measurement of energy delivered to the resist on the substrate W, the energy

sensor is preferably located as close to the substrate as possible, e.g. towards the end of the projection system PL.

A dose control system using the above described energy sensor is shown in Figure 4. This comprises a controller 60 that receives the outputs from microphone or micro-barograph 20 and sensors 21 and uses them to calculate the beam intensity at substrate level and hence the dose delivered to the resist by each pulse. An amplifier 23 is used to raise the signal level of the output of the microphone 20 so as to allow the detection of very low intensity sounds. The calculated dose is stored in memory 61 which holds a history of the doses delivered by previous pulses. Since the exposure of a given target area on the substrate is built up from the doses delivered by a plurality of pulses, the history of previous pulses making up the current exposure is used to determine any necessary correction to be applied to subsequent pulses of the exposure. The necessary corrections can be effected, for example, by adjustment of the intensity of the radiation source LA, by adjusting the opening time of a shutter SH, by adjusting the degree of opening of an iris located at an aperture plane of the illumination system, by adjusting the pulse repetition rate, by adjusting the scanning speed in a step-and-scan apparatus or any suitable combination of these parameters.

Embodiment 2

In a second embodiment of the present invention, which may be the same as the first embodiment save as described below, the microphone (or micro-barograph) 20 is located in a chamber 50 mounted to the projection system PL below the final element 40, as shown in Figure 5. The chamber 50 occupies most of the space between the final element 40 and substrate W so that the beam intensity determined form the output of the microphone 20 is as close as possible to the actual dose delivered to the resist.

Embodiment 3

A third embodiment of the present invention, which may be the same as the first embodiment save as described below, makes use of sound emitted by the substrate when a pulse of the projection beam is delivered to it. The layout of the energy sensor, shown in Figure 6, is similar to that of the second embodiment but the microphone 20 is reoriented to pick up sounds emitted by the substrate W. These sounds are caused by the sudden localized heating in the substrate and resist when a pulse of the projection beam PB strikes the substrate. Local expansion caused by the local heating gives rise to vibrations in the substrate and the emission of

sound owing to the large surface area of the substrate. These sounds are picked up by the microphone 20 and their amplitude is indicative of the amount of energy delivered to the substrate in each pulse.

Embodiment 4

A fourth embodiment of the invention is a variant of the third embodiment but adapted for use when the substrate is kept in vacuum, e.g. in a lithographic apparatus using EUV radiation. As shown in Figure 7, the microphone 20 is replaced by a vibration sensor 22 mechanically coupled to the substrate W, e.g. on the rear side. The vibration sensor 22 measures the vibrations in the substrate directly, since there is no medium to carry sound to a microphone.

Embodiment 5

In a fifth embodiment, which is otherwise similar to the fourth embodiment, vibrations in an optical element instead of the substrate are measured. When the projection beam traverses or is reflected by an optical element, e.g. mirror in the projection system of a lithographic apparatus using EUV, that has less than perfect transmissivity or reflectivity, a small amount of energy from the beam will be absorbed by the element. In the same way as with the substrate, the absorption of this energy will cause localized heating and vibration in the element. The vibration is dependent on the amount of energy absorbed, which will be a fixed or determinable proportion of the beam pulse energy, so that measurements of the vibration can be used to determine the beam energy. In the case of a mirror, the vibrations can conveniently be measured by a vibration sensor 22 mounted on the rear side, as shown in Figure 8.

Embodiment 6

In the above embodiments, sound caused by the absorption of a known or determinable fraction of the projection beam is measured to determine the intensity of the projection beam. This procedure is based on the premise that the contaminant, or deliberately introduced absorbent, is present in a known quantity and has a known effect. In the sixth embodiment, the converse is used; if the intensity of the projection beam is known or predictable, measurement of the sound caused by the passage of the projection beam can be used to detect or measure the presence of a contaminant that is absorbing the projection beam. For example, a leak of air into a purged or evacuated apparatus or the growth of an absorptive layer on an optical element can

be detected in this way. Accordingly, in the sixth embodiment microphones or other pressure or acoustic sensors are positioned in places where contamination may occur and the sounds detected with the passage of pulses of the projection beam monitored to detect any increase in contamination.

It should be noted that the principles of detecting beam intensity and detecting contamination may be combined within the same apparatus, either by use of multiple sensors or even using the same sensors. For example, under normal circumstances, the gas in a chamber may absorb 1% of the radiation passing through it and give rise to a baseline sound. However, should a contaminant cause the absorption to rise to 2% this will cause a doubling of the energy absorbed and a very substantial increase in the sound detected. A doubling of the intensity of the projection beam, which would be the other possible cause of such a large increase in the detected sound, is likely to be implausible so that the large sound increase can be attributed to an increase in contaminants rather than a change in the output of the radiation source. Similarly, trends in the detected sounds can be monitored and attributed to changes in the beam intensity or contamination by pattern matching.

Although this text has concentrated on lithographic apparatus and methods whereby a mask is used to pattern the radiation beam entering the projection system, it should be noted that the invention presented here should be seen in the broader context of lithographic apparatus and methods employing generic "patterning means" to pattern the said radiation beam. The term "patterning means" as here employed refers broadly to means that can be used to endow an incoming radiation beam with a patterned cross-section, corresponding to a pattern that is to be created in a target portion of the substrate; the term "light valve" has also been used in this context. Generally, the said pattern will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit or other device. Besides a mask on a mask table, such patterning means include the following exemplary embodiments:

- A programmable mirror array. An example of such a device is a matrix-addressable surface having a viscoelastic control layer and a reflective surface. The basic principle behind such an apparatus is that (for example) addressed areas of the reflective surface reflect incident light as diffracted light, whereas unaddressed areas reflect incident light as undiffracted light. Using an appropriate filter, the said undiffracted light can be filtered out of the reflected beam, leaving only the diffracted light behind; in this manner, the beam becomes patterned according to the addressing pattern of the matrix-adressable surface. The required matrix addressing can be performed using suitable electronic means. More information on such mirror arrays can be gleaned, for example, from

United States Patents US 5,296,891 and US 5,523,193, which are incorporated herein by reference.

- A programmable LCD array. An example of such a construction is given in United States Patent US 5,229,872, which is incorporated herein by reference.

Whilst we have described above a specific embodiment of the invention it will be appreciated that the invention may be practiced otherwise than described. The description is not intended to limit the invention.

CLAIMS

1. A lithographic projection apparatus for imaging of a mask pattern in a mask onto a substrate provided with a radiation-sensitive layer, the apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first object table for holding a mask;

a second object table for holding a substrate; and

a projection system for imaging irradiated portions of the mask onto target portions of the substrate; characterized by:

an acoustic sensor constructed and arranged to detect sounds caused by the passage of pulses of the projection beam.

2. Apparatus according to claim 1 wherein said acoustic sensor comprises a microphone or barograph located in a chamber filled with an atmosphere partially absorbent of said projection beam and traversed by said projection beam.

3. Apparatus according to claim 2 wherein said chamber is elliptical in cross-section with said projection beam passing through one focus and said acoustic sensor being positioned at the other.

4. Apparatus according to claim 2 or 3 wherein said chamber is located between the last element of said projection system and said second object table.

5. Apparatus according to claim 2, 3 or 4 further comprising a temperature sensor for measuring the temperature of said chamber.

6. Apparatus according to claim 1 wherein said acoustic sensor comprises a vibration sensor mechanically coupled to an object on which said projection beam is incident so as to measure vibrations in that object.

7. Apparatus according to claim 1 wherein said acoustic sensor comprises a microphone constructed and arranged to detect sounds emitted by an object on which said projection beam is incident.

8. Apparatus according to claim 6 or 7 wherein said object is said substrate.

9. Apparatus according to claim 6 or 7 wherein said object is an element of said projection lens.

10. Apparatus according to any one of the preceding claims further comprising a controller responsive to the output of said sensor for controlling the dose delivered by said projection bean in an exposure.

11. Apparatus according to any one of the preceding claims wherein said radiation system is adapted to supply a projection beam of radiation having a wavelength of less than about 170nm.

12. A method of manufacturing a device using a lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first object table for holding a mask;

a second object table for holding a substrate; and

a projection system for imaging irradiated portions of the mask onto target portions of the substrate; the method comprising the steps of:

providing a mask bearing a pattern to said first object table;

providing a substrate provided with a radiation-sensitive layer to said second object table;

irradiating portions of the mask and imaging said irradiated portions of the mask onto said target portions of said substrate; characterized by the step of:

using an acoustic sensor to detect vibrations caused by the passage of pulses of said projection beam.

13. A device manufactured according to the method of claim 12.

ABSTRACT

DOSE CONTROL IN LITHOGRAPHIC APPARATUS

A microphone or other acoustic sensor is used to detect sound or other vibrations caused by the passage of pulses of a projection beam. The measured vibrations may be used to determine the intensity of the projection beam or the presence of contaminants. The vibrations are caused by absorption of the beam pulses in an absorptive gas or by objects, e.g. the substrate or mirrors in the projection lens, on which the projection beam is incident.

Fig. 2

Fig. 1

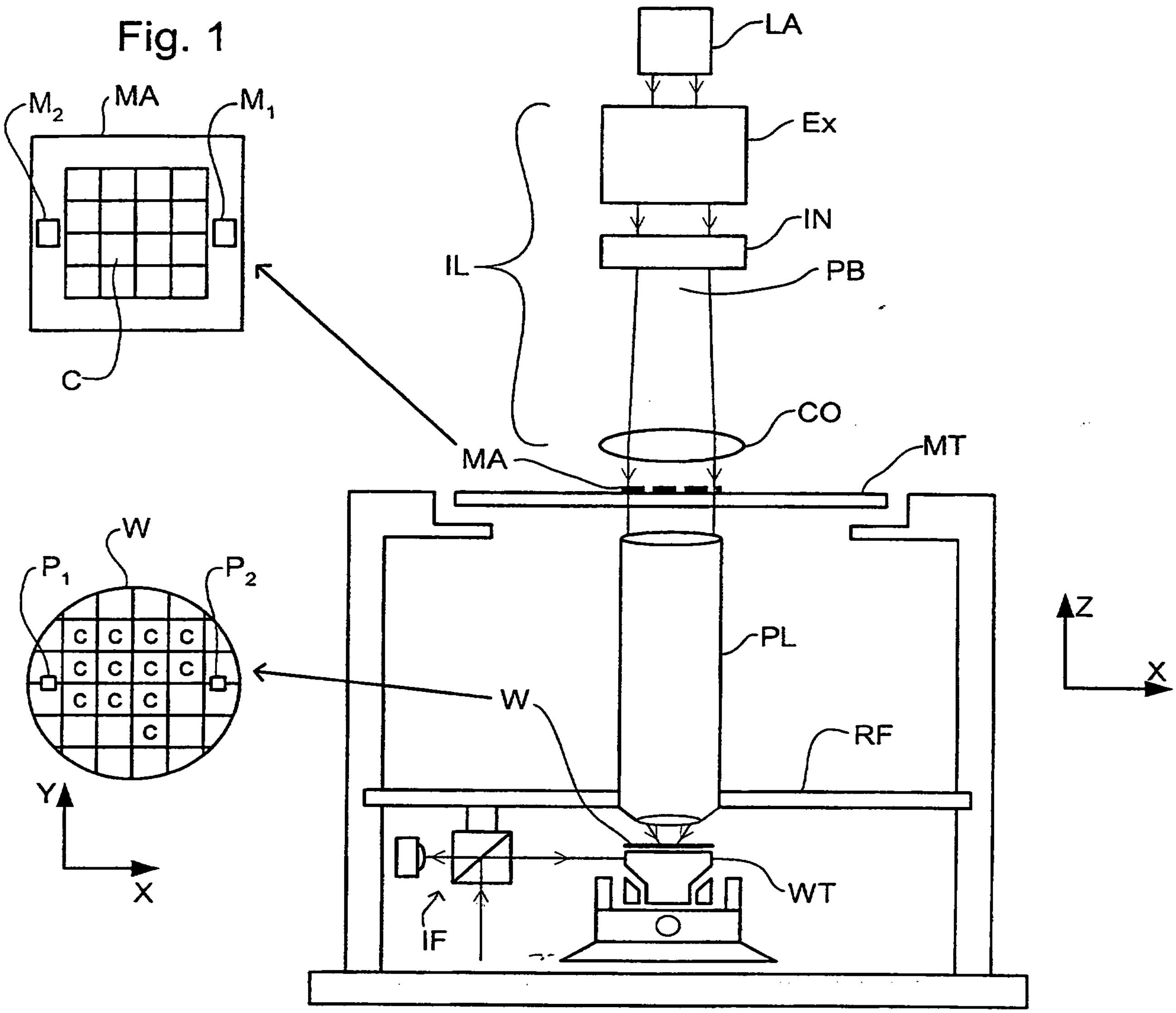

Fig. 2

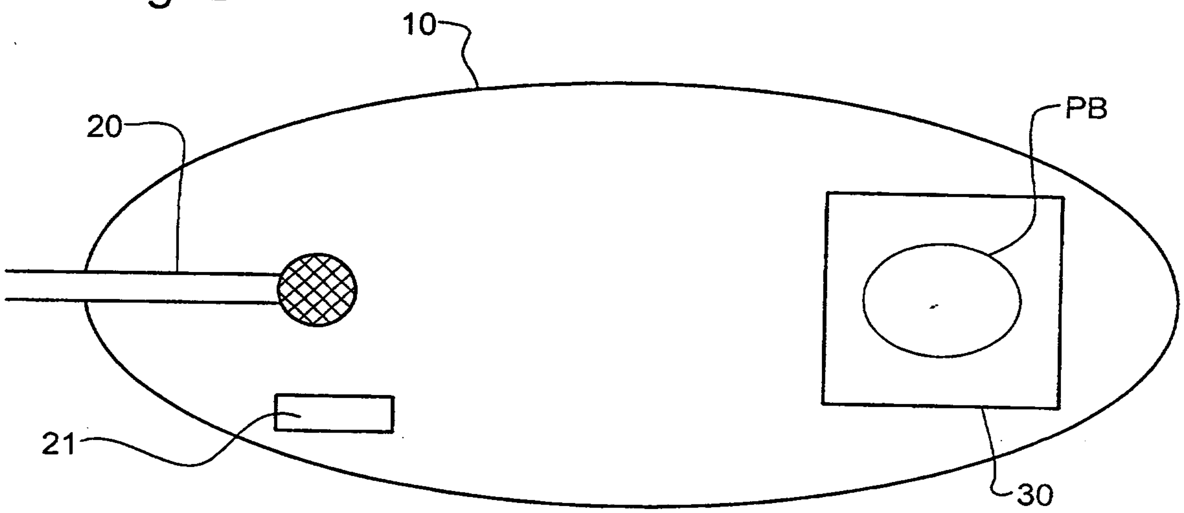

Fig. 3

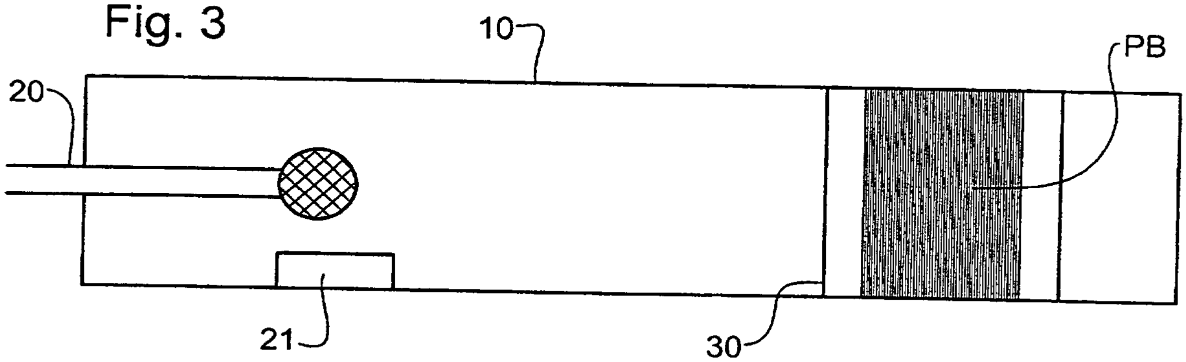

Fig. 4

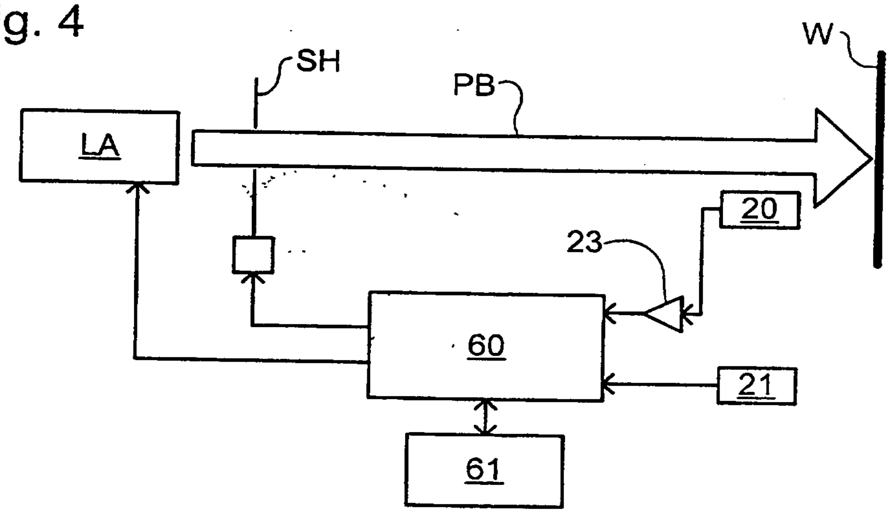

Fig. 5

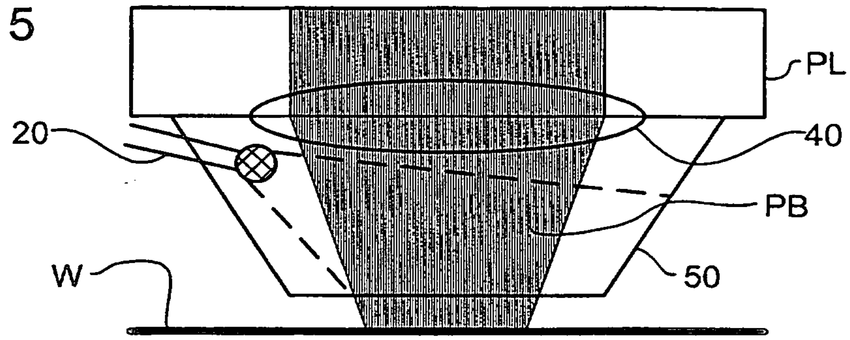

Fig. 6

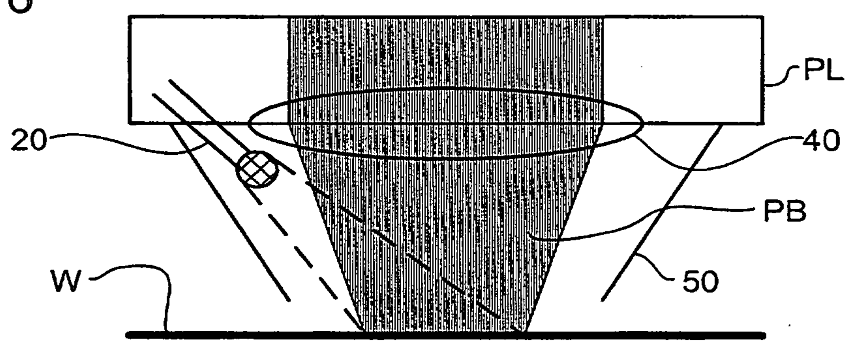

Fig. 7

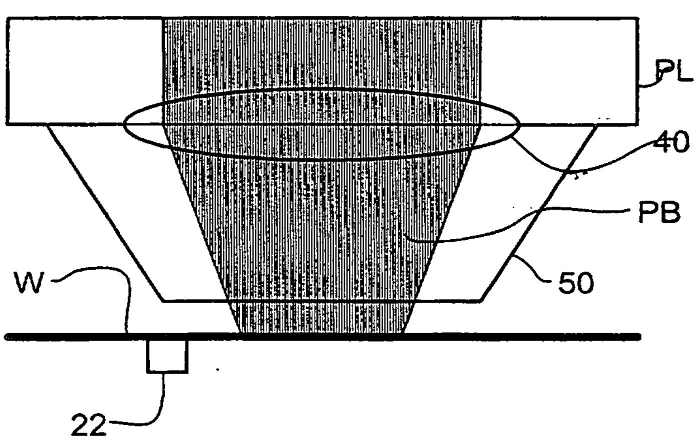

Fig. 8